

*The Excitation of  $\gamma$ -Rays by  $\beta$ -Rays.*

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The excitation of  $\gamma$ -rays by the impact of  $\beta$ -rays on different substances has been investigated by several observers. The question was first systematically examined by J. A. Gray. He showed that penetrating  $\gamma$ -rays are produced by the  $\beta$ -rays of radium E when they impinge on different materials, the amount of  $\gamma$ -radiation increasing with increase of atomic weight of the material.\* The particular disposition used in his first experiments was not suitable for the examination of any soft types of radiation which might have been excited, but in later work he showed, for the first time, that characteristic radiations were excited in the case of silver, tin, barium and cerium.† Chadwick,‡ using the balance method of Rutherford and Chadwick,§ examined whether the  $\beta$ -rays from radium B and radium C excite penetrating  $\gamma$ -rays in different kinds of matter. Definite evidence was obtained that an excited radiation amounting to about 0.5 per cent. of the primary  $\gamma$ -radiation is produced. This method, however, was not suitable for the detection of soft characteristic radiations. These general results have recently been confirmed by Starke,|| using the  $\beta$ -rays from a strong preparation of mesothorium.

In previous papers by Rutherford and the author on the analysis of the  $\gamma$ -rays from radioactive substances,¶ it has been shown that the  $\gamma$ -rays emitted by the different products can be separated into groups differing widely in penetrating power. Some of these radiations appear to be characteristic of the elements by which they are emitted and fall into one or other of the series given by Barkla.\*\* On the other hand, some of the groups of rays found do not appear to belong to either series. It was further shown in previous work that when radium C is deposited on nickel a soft radiation is given out which is entirely absorbed by 2 mm.

\* J. A. Gray, 'Roy. Soc. Proc.,' A, vol. 85, p. 131.

† J. A. Gray, 'Roy. Soc. Proc.,' A, vol. 87, p. 489.

‡ J. Chadwick, 'Phil. Mag.,' vol. 24, p. 594 (1912).

§ Rutherford and Chadwick, 'Phys. Soc. Proc.,' April, 1912.

|| Starke, 'Phys. Zeit.,' vol. 14, p. 1033 (1914).

¶ Rutherford and Richardson, 'Phil. Mag.,' vol. 25, p. 722 (1913), and vol. 26, p. 324 (1913).

\*\* Barkla, 'Phil. Mag.,' vol. 22, p. 396 (1911).

of aluminium. This soft radiation was much more readily absorbed than that emitted by radium B, and for which  $\mu = 40$  (cm.<sup>-1</sup>), but it was appreciably harder than the characteristic radiation of nickel. Moreover, when radium C was deposited on silver, little, if any, soft radiation appeared to be emitted. It seemed of importance, therefore, to examine in detail the nature of the radiation excited by the  $\beta$ - and  $\gamma$ -rays from radium B and radium C, and to examine the bearing of the results on the type of radiation emitted by different materials on which radium C is deposited.

*Experimental Arrangement.*

The apparatus used in these experiments was similar to that previously employed in the analysis of the  $\gamma$ -rays. An aluminium electroscope A, which could be filled with the vapour of methyl iodide, was arranged as shown in plan in fig. 1. The face B of the electroscope was covered with

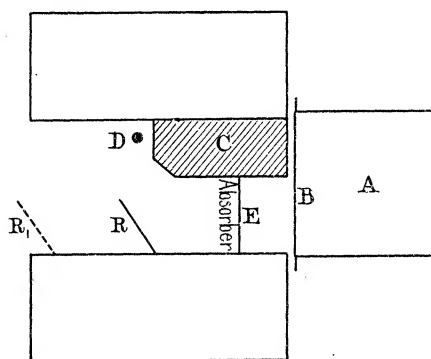


FIG. 1.

mica equivalent in stopping power for  $\alpha$ -rays to 2 cm. of air. A magnetic field was used in order to prevent the entrance of direct or reflected  $\beta$ -radiation into the electro-scope. The pole-pieces of the magnet were 16 cm. in length, and in most of the experiments the pole faces were about 9 cm. apart. All exposed metallic surfaces were covered with cardboard to reduce, as far as possible, the effect of scattered radiation.

The active source used throughout these experiments consisted of an  $\alpha$ -ray tube containing about 50 millicuries of radium emanation. Such a source, of course, emits a very intense primary  $\gamma$ -radiation, which would be sufficient to mask the effect of any excited radiation produced if suitable means were not adopted to diminish its effect, as far as possible. In order to do this, a block of lead C, 8 cm. long and 4 cm. broad, was placed as shown in the figure. The  $\alpha$ -ray tube was placed behind this block at the point D. The radiators used throughout were rectangular in shape ( $8 \times 3.5$  cm.), and were, in most cases, sufficiently thick to stop the whole of the  $\beta$ -rays. The radiator was placed, as shown at R, such that the line joining D to the centre of the radiator was parallel to the lines of force of the magnetic field. Now it is well known that a  $\beta$ -ray projected obliquely to the direction of a uniform magnetic field always moves in a helix whose axis is parallel to the lines of magnetic force.

Consequently, with the particular disposition employed, it will be seen that the  $\beta$ -rays are to a certain extent concentrated on to the radiator. Any excited  $\gamma$ -radiation produced may be therefore due either to the impact of the  $\beta$ -rays which strike the radiator, or to the effect of the primary  $\gamma$ -radiation emitted by the radium B and radium C.

*Method of Experiment.*

As the method of procedure was practically the same in all cases, it will only be necessary to describe one experiment in detail. The radiation from copper was one of the first to be examined. This element was selected since one might expect to excite in it a radiation whose effect is relatively very large when methyl iodide vapour is used in the ionisation chamber. A copper plate was placed in position at R and readings of the ionisation were taken first of all when no absorbing layers were inserted, and secondly when an aluminium sheet 2 mm. thick was inserted at E. A large diminution in the ionisation showed at once the presence of a very soft  $\gamma$ -radiation. In order to analyse the radiation which entered the electroscope it was necessary to separate out the effects due to the primary  $\gamma$ -radiation from the source, and which cannot be entirely cut out by the lead block C, and also that due to scattered and reflected radiation. To do this it is necessary to take two distinct sets of readings for the ionisation. The ionisation is measured for each particular absorbing layer first when the radiator R is in position, and then when the radiator is not present. The difference between these two readings gives the ionisation due to any excited radiation together with that due to scattered and reflected radiation. Florance\* in his recent work has shown that the latter is only slightly less penetrating than the primary radiation.

Table I gives the results obtained in one particular experiment with a copper radiator.

The curve A, fig. 2, shows the results graphically. This curve was analysed by the methods already employed in the separation of the  $\gamma$ -radiations. It will be seen that in addition to the hard scattered radiation there is also present a soft type which is entirely absorbed by less than 0.5 mm. of aluminium. Curve B shows further that the soft radiation is exponentially absorbed and that it has a mass absorption coefficient in aluminium  $\mu/\rho = 47.5$  (cm.<sup>-1</sup>). It is clear that this radiation is identical with the characteristic radiation of copper excited by X-rays, for which Barkla found the value of  $\mu/\rho = 47.7$ . The residual radiation is of a much more penetrating

\* Florance, 'Phil. Mag.', vol. 27, p. 225 (1914).

Table I.—Copper Radiator.

Thickness of aluminium absorber.	Ionisation with R in position.	Ionisation with no radiator R.	Ionisation due to excited and scattered radiation.
mm.	divs./min.	divs./min.	divs./min.
0	60.0	34.9	25.1
0.0308	52.4	34.8	17.6
0.0616	47.0	34.8	12.2
0.0924	43.4	34.1	9.3
0.123	40.9	33.9	7.0
0.185	37.5	33.0	4.5
0.246	36.4	33.0	3.4
0.56	35.8	33.2	2.6
1.12	35.2	32.8	2.4

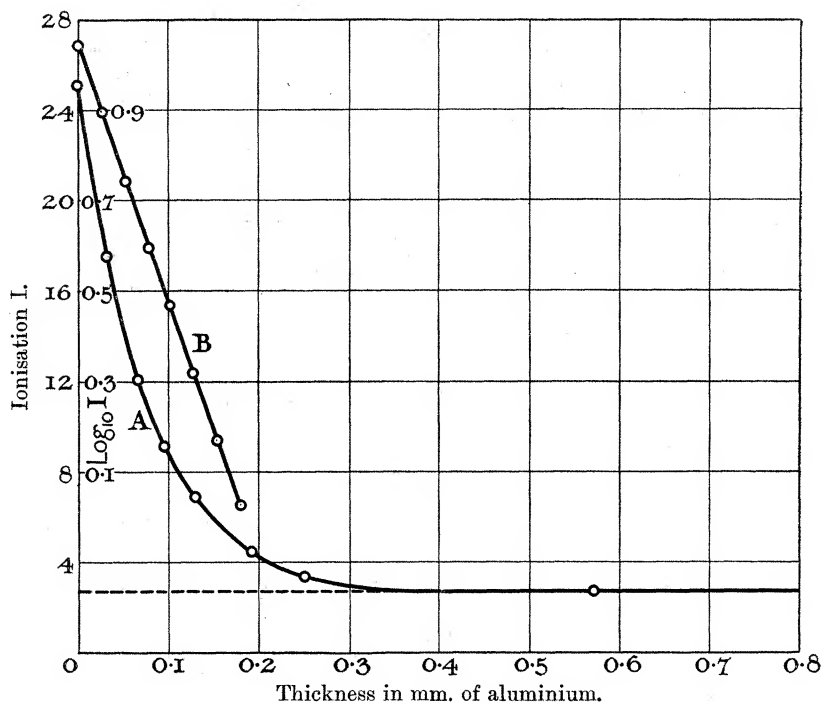


FIG. 2.

type. It had an absorption coefficient in aluminium of  $\mu = 0.2$  (cm.<sup>-1</sup>) and consisted mainly of scattered radiation.

The examination of the excited characteristic radiations has been extended to a large number of elements and compounds. The following Table gives the results obtained :—

Table II.

Element.	Atomic weight.	Mass absorption coefficient in aluminium. Series K.	Mass absorption coefficient in aluminium. Series L.	Corresponding values of mass absorption coefficients obtained by Barkla and Chapman.	
Cobalt .....	58.9	72.6		71.6	
Nickel .....	61.3	58.5		59.1	
Copper .....	63.6	47.5		47.7	
Zinc .....	65.4	39.8		39.4	
Arsenic .....	74.9	23.0		22.5	
Selenium .....	79.2	19.3		18.9	
Bromine .....	79.9	16.7		16.4	
Molybdenum .....	96.0	4.8		4.7	
Silver .....	107.9	2.5		2.5	
Tin .....	119.0	1.6		1.57	
Barium .....	137.4	0.9		0.8	
Erbium .....	166.0				
Platinum .....	195.3		22.8		22.2
Gold .....	197.2		21.4		21.6
Lead .....	207.1		17.0		17.4
Bismuth .....	208.0		16.4		16.1
Thorium .....	232.0		8.5		8.0
Uranium .....	238.0		7.8		7.5

In most cases the pure metals themselves were employed as radiators, but the oxides were used for the examination of the radiations from arsenic, cobalt, erbium, barium, thorium, and uranium, and for that from bromine a thin layer of potassium bromide was taken. The absorption was in all cases determined in aluminium of density 2.72. The numbers previously obtained by Barkla and Chapman,\* for the absorption of the characteristic radiations excited by X-rays are given in the Table. In practically all cases the agreement is very good.

It will be seen that the only radiations which it was possible to excite fall into the two groups previously found by Barkla. No evidence has been obtained of a radiation which would correspond to that emitted by radium B and for which  $\mu = 0.5$  (cm.<sup>-1</sup>) in aluminium.

The question of the relative amounts of radiation excited in each case has not, so far, been examined in detail. Gray† in his early experiments found that the actual amount of excited radiation increased with the atomic weight of the radiator. As previously pointed out, these results only refer to the penetrating types of radiation excited and do not hold in the case of the characteristic radiations here investigated. Under the experimental conditions the amount of excited radiation was a maximum for elements of low atomic

\* Chapman, 'Roy. Soc. Proc.,' A, vol. 86, p. 439.

† J. A. Gray, 'Roy. Soc. Proc.,' A, vol. 86, p. 513.

weight such as copper, and the amount decreased with increase of atomic weight. A comparative idea of the amount of characteristic radiation produced may be obtained by measuring the ionisation both with and without the radiator and comparing the increase in the ionisation for the different radiators. Under these conditions in the case of copper the increase was 42 per cent., whereas in the case of barium it was only 9 per cent. In considering these results, however, account must be taken of the relative ionisation in the methyl iodide for rays of widely different penetrating power. The whole question of the energy of the radiations cannot be conveniently discussed until the absorption of the  $\gamma$ -rays of different types in various gases has been examined. It does not imply, for example, that, because in the case of an element of small atomic weight the ionisation is magnified by means of the methyl iodide vapour, the energy of the characteristic radiation is relatively great. This problem is at present under investigation in this laboratory.

*Connection of the Results with the Origin of the Characteristic Radiations.*

Attention has already been drawn to the difficulty of separating entirely the effect due to the  $\beta$ -rays from that due to the  $\gamma$ -rays. Several experiments were made in which the  $\alpha$ -ray tube was surrounded by different materials, so that advantage might possibly be taken of any difference in the absorbability of the  $\beta$ - and soft  $\gamma$ -rays. The difference is not, however, sufficiently great to give any definite results. It will be seen, however, that if the excited radiation is due to the impact of the  $\beta$ -rays and not to the  $\gamma$ -rays, then if the radiator is moved into some position  $R_1$  (see fig. 1) the  $\beta$ -rays emitted by the source are no longer concentrated on to the radiator, and the excited radiation should be entirely cut off. Experiments made with varying positions of the radiator showed conclusively that the excited radiations produced are almost entirely due to the impact of the  $\beta$ -rays. It was at first supposed that the excitation of the rays might be due to the  $\gamma$ -rays emitted by radium B and for which  $\mu = 40$ . This seemed probable, since these soft  $\gamma$ -rays are similar in character to penetrating X-rays used by previous workers for the excitation of characteristic radiations. The results show, however, that any effect due to the  $\gamma$ -rays must be very small compared with that due to the  $\beta$ -rays.

It is interesting to note here also that the effect of the  $\alpha$ -rays in producing excited  $\gamma$ -radiation must be relatively very small. Chadwick first showed that a small amount of  $\gamma$ -radiation is produced when the  $\alpha$ -rays of radium C impinge on plates of different material.\* The amount of this radiation was,

\* J. Chadwick, 'Phil. Mag.', vol. 25, p. 193 (1913).

however, too small to permit of analysis. In later experiments Russell and Chadwick\* distilled polonium on to a copper plate, and were able to detect a very small amount of radiation which appeared to be the characteristic radiation of copper excited by  $\alpha$ -rays. In order to examine whether the  $\alpha$ -rays from radium C produced any appreciable amount of  $\gamma$ -radiation with the experimental arrangement shown in fig. 1, the ionisation was first of all measured when air was between the source D and the radiator R, the radiator being placed just beyond the range of the  $\alpha$ -particles emitted by radium C. A stream of hydrogen was then directed so that the air between D and R was displaced. By this means the range of the  $\alpha$ -rays was increased and the rays were able to strike R. No measurable increase of the ionisation was observed, thus showing conclusively that in these experiments the effect of the  $\alpha$ -rays is negligible compared with the  $\beta$ -rays in the production of excited  $\gamma$ -radiations.

*Experiments with the Penetrating  $\gamma$ -Rays from Radium C.*

The previous experiments have shown that whilst the  $\beta$ -rays from radium B and radium C excite a large amount of characteristic radiation the  $\gamma$ -rays from radium B do not. Recently Florance† has examined the question of the excitation of  $\gamma$ -rays by the penetrating  $\gamma$ -rays emitted by radium C. His experiments would appear to indicate that in one case only, namely, in that of lead, was any such radiation very definitely observed. A slight modification in the arrangement of the above experiment seemed suitable for testing this point. The source used in this experiment consisted, as before, of an  $\alpha$ -ray tube containing about 50 millicuries of radium emanation. In this case, however, the tube was surrounded by a cylinder of lead 8 mm. thick, a thickness sufficiently great to absorb entirely the  $\gamma$ -rays emitted by radium B. In order to reduce the direct effect of the  $\gamma$ -radiation to a minimum, a small pole-piece was used as shown in fig. 3, and the piece of iron which had been removed was replaced by a large block of lead. By this means the direct effect was reduced to a considerable degree. A large radiator R was placed in the position shown, and readings of the ionisation were taken both with and without the radiator, as in the previous experiments. No definite evidence of the production of any excited radiation was observed under the experimental conditions. This was no doubt due to the fact that the amount of radiation excited by the hard  $\gamma$ -rays is relatively much feebler in intensity than that produced by the  $\beta$ -rays. The effects could only therefore be measured by means of a much more sensitive arrangement,

\* Russell and Chadwick, 'Phil. Mag.,' vol. 26, p. 113 (1914).

† Florance, 'Phil. Mag.,' vol. 27, p. 225 (1914).

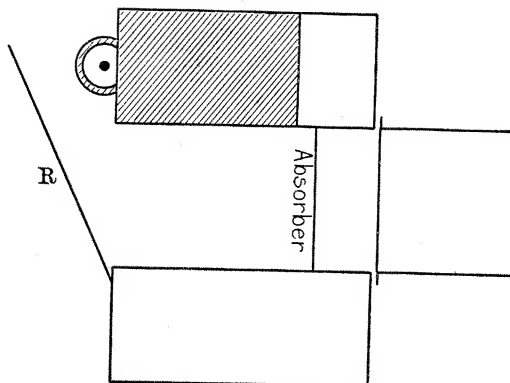


FIG. 3.

as, for example, by the use of a balance method such as was adopted by Chadwick and Florance.

*Analysis of the  $\gamma$ -Radiation excited by Radium C in Nickel.*

The previous experiments show conclusively that the  $\beta$ -rays of radium B and radium C excite the characteristic radiations of those materials on which they impinge. It has already been pointed out that the radiation emitted when radium C is deposited on nickel is not the characteristic radiation of nickel but is appreciably harder. It seemed possible to complete the analysis by depositing radium C on some material, such as aluminium or carbon, which emits a characteristic radiation so easily absorbed that it could not be detected under the experimental conditions.

In order to obtain a deposit of radium C on different materials a very active nickel wire was first obtained by von Lerch's method. The deposit of radium C was then distilled from the nickel on to the material required. The distillation was carried out in an atmosphere of hydrogen at a temperature of  $700^{\circ}$  C. The furnace used for this purpose was the same as that previously used by Russell and Chadwick\* and described by them in detail. The distillation could be quickly and efficiently carried out.

The absorption curve for the  $\gamma$ -radiation emitted when radium C was deposited on a nickel wire was first of all determined. This was found in the usual manner, the electroscope shown in fig. 1 being used, and the lead block C in this case being of course removed. The curve obtained is shown in fig. 4, curve A. The residual hard radiation due to the radium C is indicated by the dotted line. A deposit of radium C was then obtained on a thin aluminium strip and the absorption curve for the radiation emitted

\* Russell and Chadwick, 'Phil. Mag.', vol. 27, p. 112 (1914).



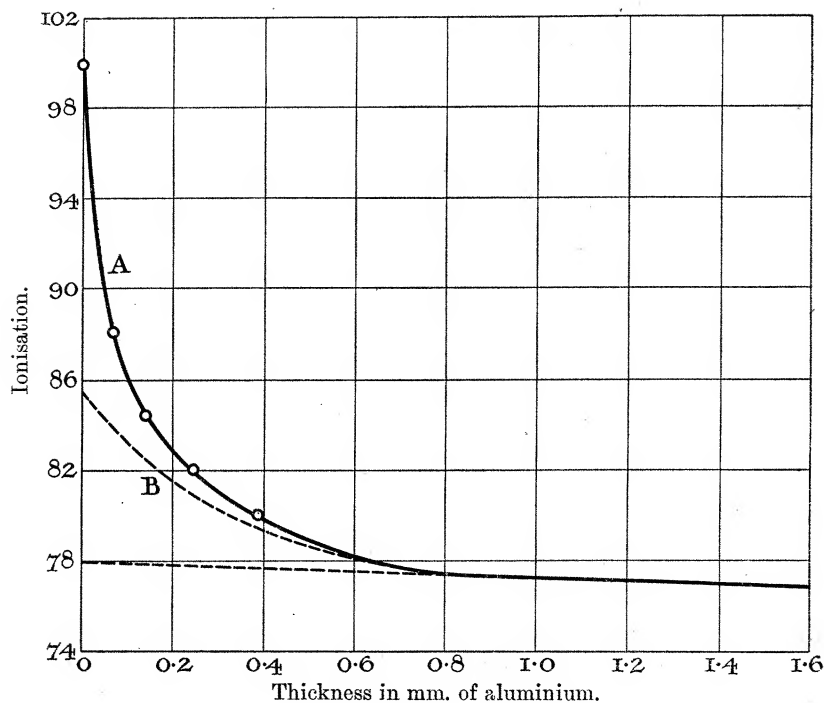


FIG. 4.

was found under the same conditions as before. The curve obtained is shown in fig. 5. It will be seen from this curve that a small proportion of a soft radiation, amounting to about 7 per cent. of the total radiation, is

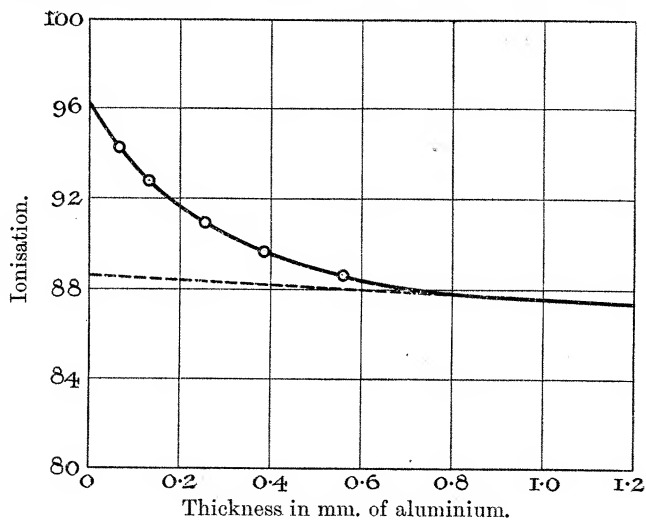


FIG. 5.

given out even when radium C is deposited on aluminium. The analysis of this radiation showed that its absorption coefficient in aluminium is  $\mu = 40$ , and it is probably identical in character with that emitted by radium B. This radiation cannot be excited in the aluminium and would seem to be due to radium C. In order to confirm this conclusion some radium C was distilled on to a thin layer of graphite and the absorption curve was determined as before. The curve obtained was identical with that found in the case of radium C deposited on aluminium, the amount of soft radiation emitted being the same in both cases. The rate of decay of the active material was in every experiment carefully determined. The results showed that the deposit consisted of pure radium C and did not contain a detectable amount of radium B. This evidence clearly indicates therefore that radium C, in addition to the penetrating radiation for which  $\mu = 0.115$ , also emits a small amount of soft radiation for which  $\mu = 40$ .

In attempting to analyse the radiation from nickel it is, of course, necessary to separate the effect due to the soft radiation from the radium C. This is easily done since the absorption curves were obtained under exactly the same conditions. Fig. 4 shows the method of analysis. Curve A is the nickel absorption curve and B is the aluminium curve. The difference between the ordinates gives us the effect of the radiation excited in the nickel. If these be plotted it is found that the absorption coefficient is the same as that of the characteristic radiation of nickel. Experiments with a deposit of radium C on copper and silver give similar results.

#### *Summary.*

(1) The general nature of the radiations excited when the  $\beta$ - and  $\gamma$ -rays of radium B and radium C impinge on different materials has been examined. Evidence has been obtained which shows that the excitation of characteristic radiations is mainly due to the  $\beta$ -rays and not to the  $\gamma$ -rays.

(2) The question of the excitation of characteristic  $\gamma$ -rays by the penetrating  $\gamma$ -rays emitted by radium C has also been examined, but no certain evidence has been obtained of the production of any such radiations.

(3) It has been shown that radium C, in addition to the penetrating type of radiation for which  $\mu = 0.115$ , emits also a small amount of soft  $\gamma$ -radiation similar in type to that shown by Rutherford and Richardson to be emitted by radium B and for which  $\mu = 40$  in aluminium.

(4) The amount of  $\gamma$ -radiation excited by the  $\alpha$ -rays of radium C is negligible compared with that excited by the  $\beta$ -rays.

(5) When radium C is deposited on different materials a soft radiation is

emitted which consists of the characteristic radiation of the material, excited by the  $\beta$ -rays of radium C, together with the soft radiation emitted by radium C.

I wish to express my sincere thanks to Sir Ernest Rutherford for the constant help and valuable advice which he has given to me throughout these experiments.

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*Electrification of Water by Splashing and Spraying.*

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The experiments of Lenard\* and Sir J. J. Thomson† on the electrification produced by the splashing of pure water and other liquids are well known. It was found that distilled water when splashed at a metal obstacle took up a positive charge, giving a negative charge to the air. Very dilute solutions of different substances gave very remarkable results, the sign and magnitude of the charge on the liquid depending on the dissolved substance and the degree of concentration of the solution. In all cases the electrification ultimately approached zero as the strength of the solution increased, so that for solutions of quite moderate strength the effect was inappreciable. Simpson‡ has shown that if drops of distilled water are allowed to fall into a vertical jet of air of sufficient velocity, the drops are broken up and acquire a positive charge. Investigations of the electrification produced in the air when splashing takes place have been made by Kähler,§ Aselmann|| and Simpson. Similar investigations have been made in connection with bubbling and spraying of liquids by Townsend,¶ Sir J. J. Thomson,\*\* Kusters††, Eve‡‡ and M. Bloch.§§ A complete account of the subject will be found in a memoir by J. J. Rey.||||

\* Lenard, 'Wied. Ann.,' vol. 46, p. 584 (1892).

† J. J. Thomson, 'Phil. Mag.,' vol. 37, p. 341 (1894).

‡ Simpson, 'Phil. Trans.,' vol. 209, p. 379 (1909).

§ Kähler, 'Ann. der Phys.,' vol. 12, p. 1119 (1903).

|| Aselmann, 'Ann. der Phys.,' vol. 19, p. 960 (1906).

¶ Townsend, 'Camb. Phil. Soc. Proc.,' vol. 9, part 5 (1898).

\*\* J. J. Thomson, 'Phil. Mag.,' p. 352 (1902).

†† Kusters, 'Wied. Ann.,' vol. 69, p. 12 (1899).

‡‡ Eve, 'Phil. Mag.,' vol. 14 (1907).

§§ M. Bloch, 'Comptes Rend.,' vol. 145, p. 54 (1907).

|||| Rey, 'Sur l'Ionisation de l'Air par les Chutes d'Eau,' Gauthier-Villars, 1912.